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Filtration and Excretion by Zebra Mussels: Implications for Water Quality Impacts in Lake Pepin, Upper Mississippi River

by W. F. James, J. W. Barko, M. Davis, H. L. Eakin, J. T. Rogala, and A. C. Miller

PURPOSE: This technical note describes the impacts of filtration and soluble nutrient excretion by zebra mussels on water quality in Lake Pepin, Upper Mississippi River.

Background: Because they are filter-feeders, zebra mussels can significantly reduce concentrations of seston (i.e., suspended particulate matter including algae and bacteria), resulting in increased water clarity (Reeders and de Vaate 1990; Holland 1993; Fanslow, Napela, and Lang 1995; Madenjian 1995; Klerks, Fraleigh, and Lawniczak 1996). Conversely, zebra mussels can impair water quality by excreting soluble nutrients and by increasing sediment biological oxygen demand (Andersson, Graneli, and Stenson 1988; Effler and Seigfried 1994; Gardner et al. 1995; Heath et al. 1995; Holland, Johengen, and Beeton 1995; Mellina, Rasmussen, and Mills 1995; Arnott and Vanni 1996; Effler et al. 1996; James, Barko, and Eakin 1997a; Effler et al. 1997). Since positive and negative effects on water quality can vary with differences in hydraulic residence time, thermal structure, availability of dissolved oxygen, seston loadings, and biotic variables, there is a need to determine the effects of zebra mussel filter-feeding activities on water quality conditions in aquatic systems. Relationships between seston filtration and soluble nutrient excretion were examined over a range of zebra mussel shell lengths (6 to 32 mm). This information was used in conjunction with zebra mussel shell length frequency distribution and areal estimates of zebra mussel population density to predict overall areal filtration and soluble nutrient excretion rates in Lake Pepin, Upper Mississippi River. Zebra mussels were first found in Lake Pepin in 1994 and have increased in population density considerably over the last 4 years.[1]

METHODS: Zebra mussels, collected from Lake Pepin, were carefully removed from rock substrate and incubated in a flow-through water bath (120 L at 18 °C) in the laboratory for 2 weeks prior to initiation of the experiment. Water for the bath, containing natural seston as a food source, was collected daily from a nearby reservoir (Eau Galle Reservoir, WI). The water had an average viable chlorophyll *a* content of >50 µg/L and consisted primarily of diatoms (*Stephanodiscus* spp.). This food source flowed into the incubation bath constantly to establish a residence time of about 0.5 day (i.e., flushed twice a day).

Simultaneous filtration of chlorophyll and excretion of soluble nutrients were examined over a 24-hr period in laboratory microcosms. Microcosms consisted of 1-L spoutless beakers with stoppers. Constant, gentle mixing to keep seston in suspension was maintained in each microcosm with magnetic stirring motors and magnetic stir bars. Plastic tripods were placed in each microcosm to hold the zebra mussels. The zebra mussels used for the experiment ranged in length from ~ 6 mm to 32 mm. Three zebra mussels were randomly chosen from each of five size classes (6-10 mm, 11-15 mm, 16-20 mm, 21-25 mm, >25 mm) for the experiment. In addition, replication (two to three reps) was performed for randomly chosen lengths of 14, 15, 17, and 29 mm. Overall,

1 Personal Communication. 1999. M. Davis, Minnesota Department of Natural Resources, Lake City, MN.

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21 microcosms contained lake water and 1 zebra mussel, while three microcosms served as controls (i.e., no zebra mussels).

At hours 0, 3, 6, 9, 12, and 24, samples were collected and analyzed for viable chlorophyll, total N and P, ammonia-N (NH_3-N), nitrate-nitrite-N (NO_2NO_3-N), and soluble reactive P (SRP; American Public Health Association (1992)). Organic N was calculated as total N minus NH_3-N and NO_2NO_3-N. Organic P was calculated as total P minus SRP. Rates of chlorophyll filtration and soluble nutrient excretion, corrected for control rates, were calculated on an ash-free dry mass ($\mu g\ g\ AFD\ mass^{-1}\ h^{-1}$) basis. For AFD mass, zebra mussels were dried at 40 °C to a constant mass and then ashed in a muffle furnace at 500 °C for 2 hr. Shell lengths were measured to the nearest 1 mm.

In July 1997, eight transects were established perpendicular to the shoreline along the longitudinal axis of Lake Pepin for zebra mussel sampling purposes (Figure 1). Samples were collected along each transect at 1-m depth intervals (surface to bottom) using SCUBA. Five randomly selected 0.25-m^2 quadrats were sampled at each depth interval. Samples were collected from quadrats using a 4-in.-diam suction dredge that delivered bottom substrate to the boat. Zebra mussels were counted

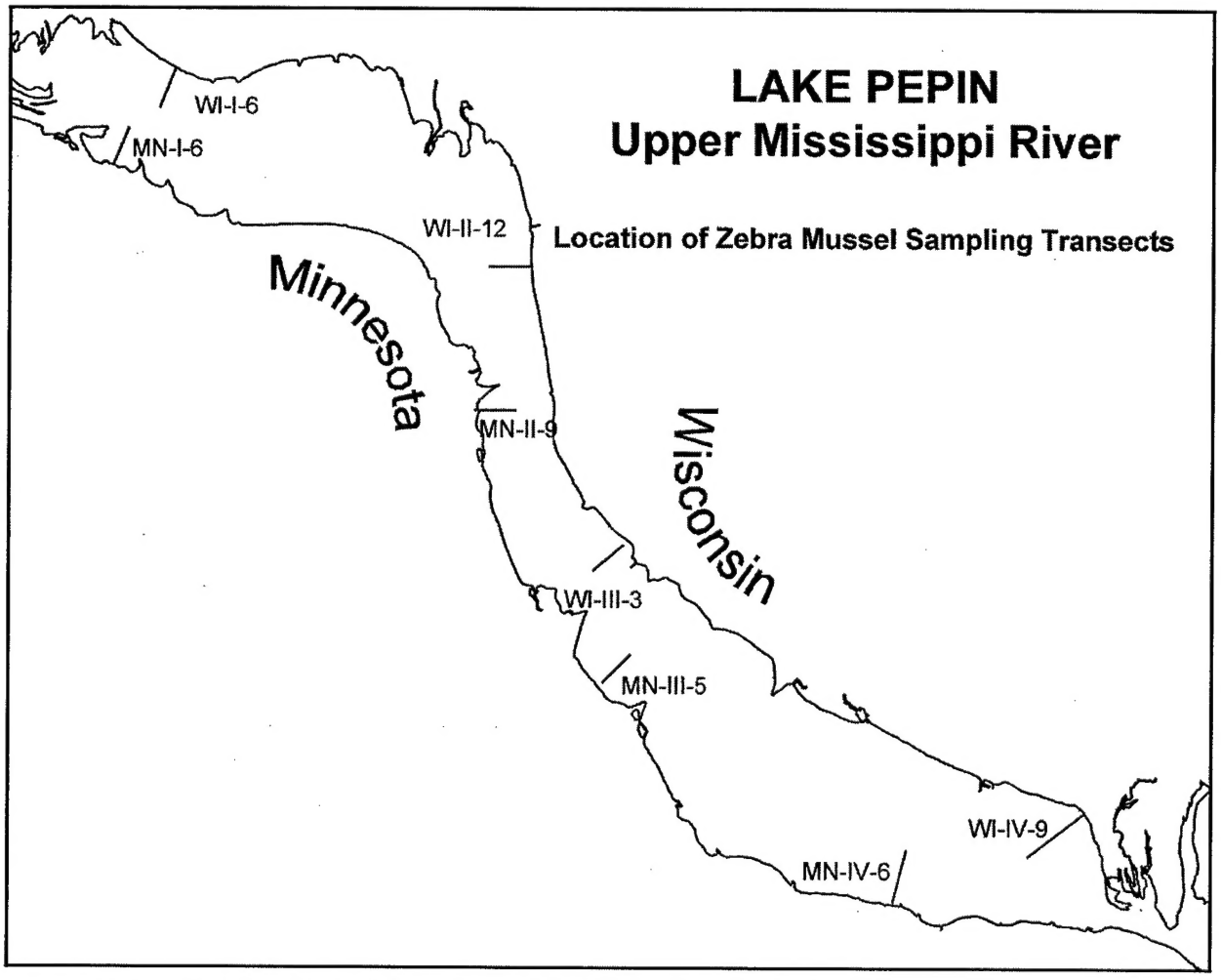

Figure 1. Map of Lake Pepin (Upper Mississippi River) showing zebra mussel sampling transects

to determine density (individuals/m^2). Shell length frequency distributions were determined from subsamples collected from each transect.

Field information on mean (n=5) zebra mussel population density at each depth interval was multiplied by the shell length frequency distribution measured for each transect to estimate population density over the ranges of shell lengths. Relationships between shell length and chlorophyll filtration or soluble nutrient excretion developed in the laboratory were used to estimate filtration and excretion (mg m^{-2} d^{-1}) by zebra mussels for each depth interval of each transect. The percent of the total surface area of Lake Pepin was computed for each depth interval along each transect and multiplied by areal filtration and excretion rates to determine area-weighted rates for each transect. From this information, grand mean rates of filtration and excretion, weighted with respect to area, were computed for the entire lake. Included in this lakewide computation were areas not occupied by zebra mussels as well as areas occupied by zebra mussels.

RESULTS AND DISCUSSION

Laboratory Determinations. Changes in concentrations of chlorophyll, nitrogen, and phosphorus during the microcosm study are shown in Figure 2. Chlorophyll (Figure 2a), organic P (Figure 2b), and organic N (Figure 2c) concentrations declined in a linear manner over time, indicating filtration of seston by zebra mussels. However, seston concentration declines coincided with increases in SRP and NH_3-N , indicating excretion of some of the ingested seston in the form of soluble nutrients (Figures 2b and 2c, respectively).

Rates of chlorophyll filtration, weighted with respect to zebra mussel ash-free dry mass, were greatest for small zebra mussels (shell length 10 mm) and declined in a nonlinear manner as shell length increased (Figure 3). Filtration of organic N and P, and excretion of NH_3-N and SRP, followed a similar nonlinear pattern (Figures 4 and 5).

Population Demography in Lake Pepin. In Lake Pepin, zebra mussel densities were generally greatest in the downstream region of Lake Pepin along the Minnesota side of the lake, with densities ranging from 0.8 to 22,595 individuals/m^2 in 1997 (Figure 6). High densities near the outflow of Lake Pepin were found at depths down to 9 m. Zebra mussels were found at all transects, but densities were much lower upstream of WI-III-3 (Figure 6) and confined to depths less than 3 m. The grand mean density, weighted with respect to area (i.e., including depths that did not have zebra mussel populations), was 148 individuals/m^2 (± 120 S.E.).

Estimated Impacts of Zebra Mussels on Water Quality in Lake Pepin. Estimated lakewide filtration and soluble nutrient excretion rates for zebra mussels in Lake Pepin are shown for the summer of 1997 in Table 1. Although overall zebra mussel densities in Lake Pepin were low compared to other systems (Effler et al. (1996) and references cited within), lakewide chlorophyll filtration by zebra mussels was nearly equivalent to loading of chlorophyll to Lake Pepin via external sources during the summers of 1994-1996 (10 mg m^{-2} d^{-1}; James, Barko, and Eakin (1997b)). Using summer concentrations of chlorophyll in the water column of Lake Pepin measured in 1994-96 (grand mean = 13 µg L^{-1} ± 0.8 S.E.; James, Barko, and Eakin (1997b)), we estimated a chlorophyll turnover was estimated at ~ 11 days at the zebra mussel densities observed

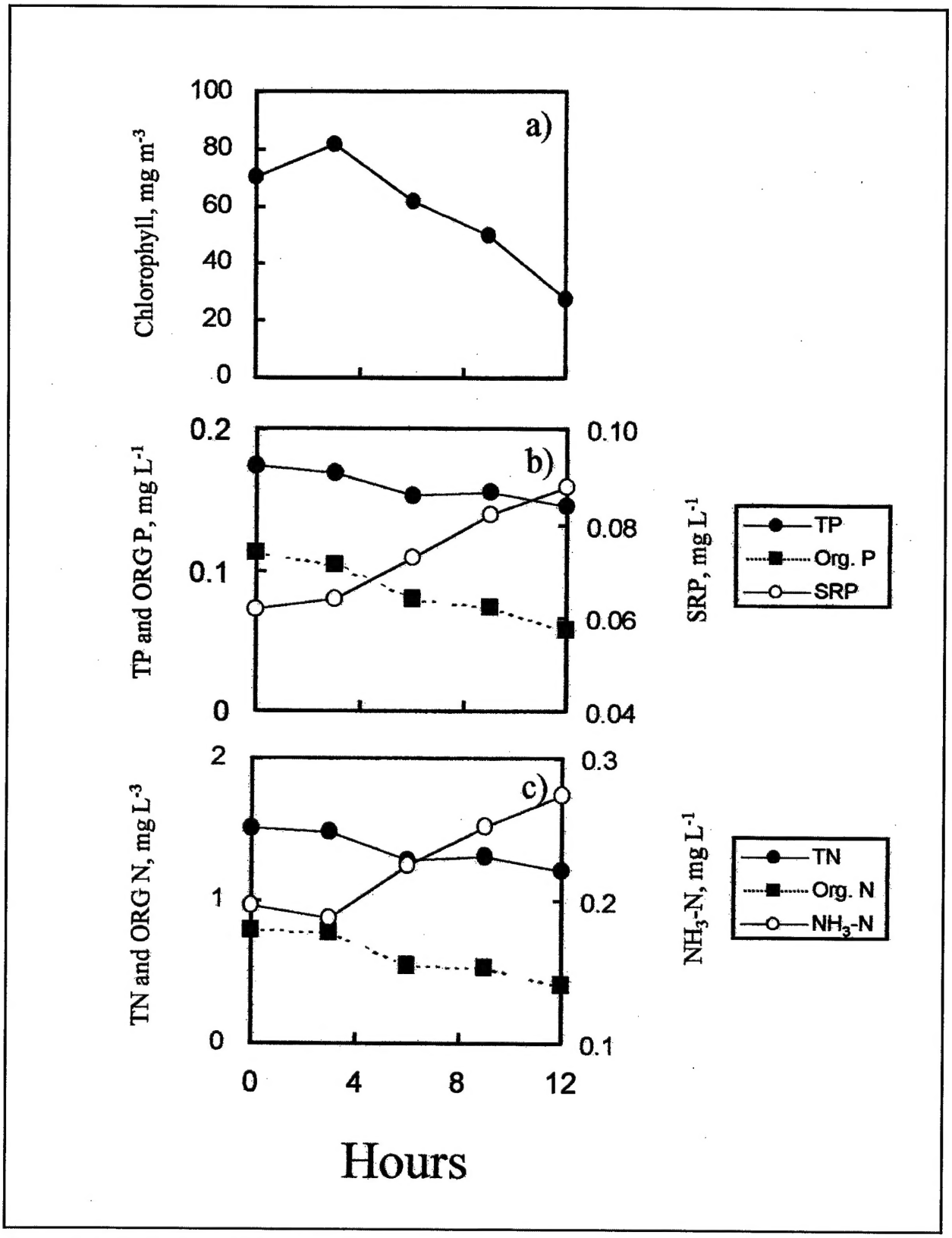

Figure 2. Variations in chlorophyll, phosphorus, and nitrogen species as a function of time in a laboratory microcosm containing lake water and a zebra mussel

in 1997. This estimate does not factor in chlorophyll turnover associated with productivity and death via predatory and nonpredatory losses.

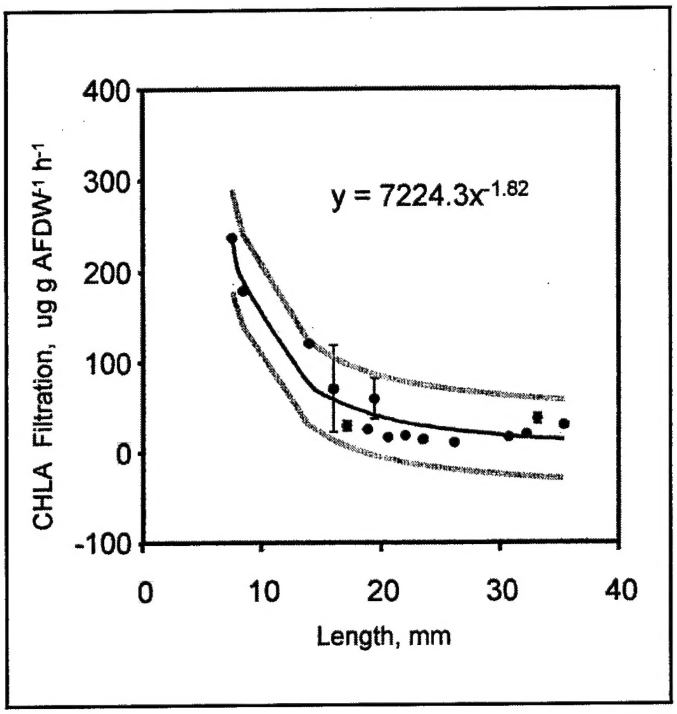

Figure 3. Zebra mussel length versus chlorophyll filtration by zebra mussels. Gray lines represent upper and lower 95-percent confidence limits. Vertical bars represent 1 S.E. (n = 3)

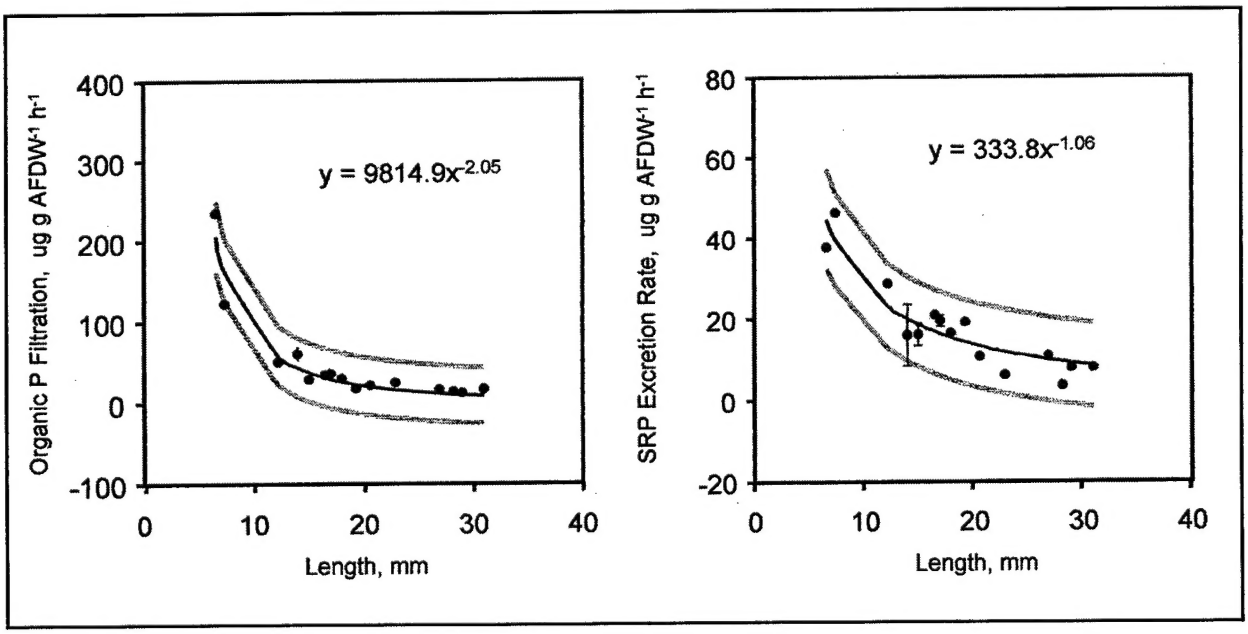

Figure 4. Zebra mussel length versus organic P filtration (left) and SRP excretion (right) by zebra mussels. Gray lines represent upper and lower 95-percent confidence limits. Vertical bars represent 1 S.E. (n = 3)

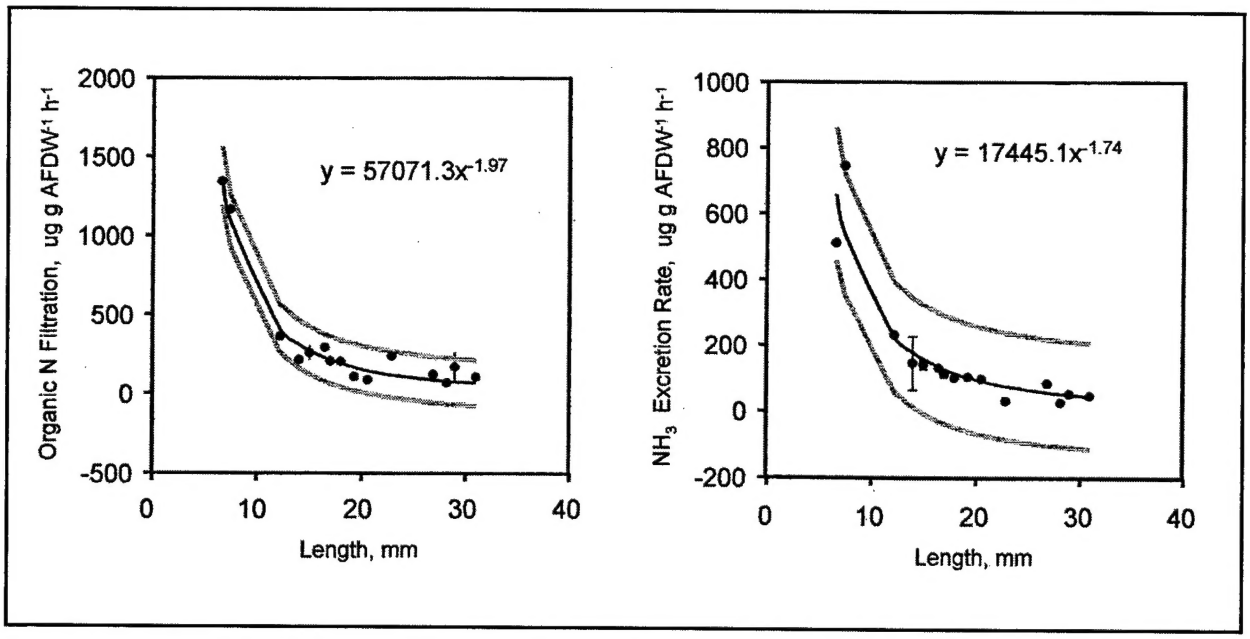

Figure 5. Zebra mussel length versus organic N filtration (left) and ammonia excretion (right) by zebra mussels. Gray lines represent upper and lower 95-percent confidence limits. Vertical bars represent 1 S.E. (n = 3)

Table 1
Lakewide Estimates of Chlorophyll Filtration and Soluble Reactive Phosphorus and Ammonia Excretion by Zebra Mussels in Lake Pepin (Upper Mississippi River)*

Parameter	Level
Chlorophyll filtration, mg m^{-2} d^{-1}	7.1 (6.0)
Ammonia excretion, mg m^{-2} d^{-1}	21.8 (17.4)
Soluble phosphorus excretion, mg m^{-2} d^{-1}	3.0 (2.3)
*Grand means (± 1 S.E.) were calculated over all depths and areas of Lake Pepin.	

Areal excretion of soluble phosphorus by zebra mussels in Lake Pepin (Table 1) was equivalent to rates of internal P loading from anoxic sediments determined for a variety of aquatic systems (Nürnberg et al. 1986). In addition, soluble N and P excreted by zebra mussels in Lake Pepin are directly available for uptake and growth by algae, particularly unpalatable nuisance cyanobacterium. The N:P ratio of excreted soluble material was low (~ 3:1 molar ratio), similar to the findings of Arnott and Vanni (1996), which could also favor cyanobacterium dominance in this system. However, current overall impacts of zebra mussels on P recycling were low compared to mean external P loadings from the watershed (grand mean = 59.6 mg m^{-2} d^{-1} ± 8.1 S.E.) and mean internal P loadings from oxic profundal sediments (grand mean = 7.5 mg m^{-2} d^{-1} ± 0.9 S.E.) measured in Lake Pepin for the summers 1994-96 (James, Barko, and Eakin 1997b). In other systems, P recycling via zebra mussel excretion has had much larger impacts on the P economy (Effler et al. 1996; Arnott and Vanni 1996), due to greater zebra mussel infestation in these systems compared to Lake Pepin.

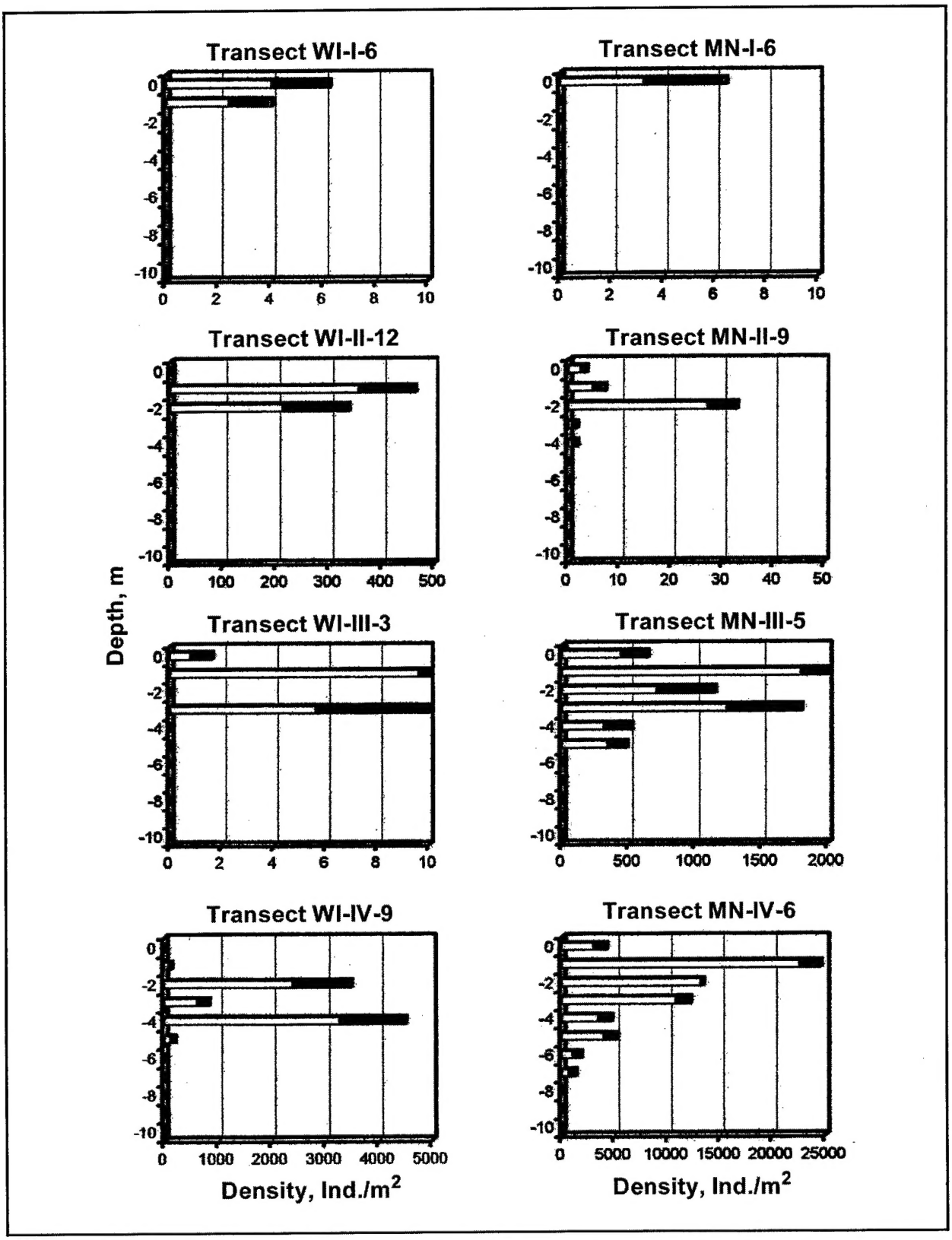

Figure 6. Variations in zebra mussel density as a function of depth for various transects in Lake Pepin. White bars represent mean density while black bars represent 1 S.E.

Results suggest that zebra mussels are currently having a modest impact on phytoplankton dynamics and P and N recycling in this system. However, population increases in future years will probably exacerbate these impacts. Lakewide estimates of zebra mussel filtration and excretion need to be combined with models that simulate phytoplankton productivity and zebra mussel population dynamics (growth, predation, death, etc.) in order to better understand and predict zebra mussel impacts on water quality.

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POINTS OF CONTACT: This technical note was written by Messrs. William F. James and Harry L. Eakin of the U.S. Army Engineer Waterways Experiment Station Eau Galle Aquatic Ecology Laboratory; Drs. John W. Barko and Andrew C. Miller, WES; Mr. Mike Davis of the Minnesota Department of Natural Resources; and Mr. James T. Rogala of the U.S. Geological Survey. For additional information contact Mr. James, (715-778-5896, *jamesw1@sin.bright.net*), or the program managers of the Water Quality Research Program, Dr. Barko (601-634-3654, *barkoj @wes.army.mil*) or Mr. Robert C. Gunkel (601-634-3722, *gunkelr@wes.army.mil*). This technical note should be cited as follows:

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